8/PRTS

09/341232
510 Rec'd PCT/PTO 06 JUL 1999

[2345/79]

METHOD FOR GENERATING A NETWORK

Field Of The Invention

~~Background of the Invention~~

The present invention relates to ~~concerns~~ a method for generating and optimizing a network, in particular a telecommunications, water, long-distance heat supply, or power network.

Background Information

Supply, telecommunications, or, for example, computer networks are very difficult for a person to set up by hand once they have grown beyond a certain size. When setting up a network, therefore, the most important consideration is its proper functioning. Once the network has been set up, it can be optimized only at points. In most cases, serious errors can no longer be corrected later on.

Depending on the network type and layout, the widest variety of technologies can be used. Network planners usually have multiple components at their disposal for solving a specific network problem. In the case of telecommunication networks, planners must, among other things, decide whether to use a copper or fiber-optic cable for a specific connection. They must also choose among a wide variety of copper and fiber-optic cable types, all of which vary in terms of their capacities, i.e. transmission rates, number of lines per cable, and maximum possible transmission ranges.

Up to now, network plans for telecommunication networks that will provide coverage for a specific territory have almost always been drawn up manually by experienced network planners. As mentioned above, proper network functioning is the primary concern when drawing up such plans. A network that has been technically optimized and has the most cost-effective layout

EL 303285469US

cannot be set up using the currently known network generation methods.

The conventional method for setting up a telecommunications network is described below, only the most important principles being explained. Figure 1 shows a territory 1 having individual blocks 2 of houses to be supplied from an exchange (HVK) 7. Blocks 2 have individual users 3, whose phone line requirements 4 are indicated. For purposes of illustration, users 3 in this example do not require any services other than phone lines. Blocks 2 are separated from one another by streets 5 and street intersections 6. As shown in Figure 2, the network planner has divided territory 1 into areas A through E on the basis of the planning rules established in the past by the carrier and of his store of experience, multiple city blocks, such as Al and A2, usually being combined into one area. These areas are referred to below as cable distribution areas. The territory is divided into cable distribution areas on the basis of the technology to be used and on the basis of the cable typologies defined in the individual countries. The technology determines the maximum and optimum size of the individual cable distribution areas. In the present example, the network planner has selected, e.g., copper cables, it being possible for one copper cable to have different pairings, such as 10, 20, 50, 75, 100, 150 or 200 copper pairs (CuDA). The copper cable transmission range is sufficient for all users, and the maximum capacity of a cable distributor 8 may be 1 00 copper pairs. The network planner then establishes the locations of cable distributors 8 (KVZA - KVZE) from which the distribution cables (VzK) containing the phone lines are run to individual users 3 along the possible routes, i.e. along the sidewalks and underneath intersections 1 1, as shown in Figure 3. The telephone lines

of the particular area, which are bundled into main cables (Hk) 9 are run directly to exchange 7 from cable distributor 8 of the area. If possible, cables 9 are run along existing cable routes of the other areas in order to reduce the cost of laying cables.

As shown in Figure 2, area A must be supplied with at least 68 phone lines, area B with at least 72 phone lines, area C with at least 78 phone lines, area D with at least 57 phone lines, and area E with at least 49 phone lines. This means that multiple copper distribution cables, whose utilization depends on the number of copper pairs needed as well as on the cable typology, must be laid in the individual areas. For example, a 20-pair copper distribution cable is needed for one side of a city block A1 and a 50-pair copper distribution cable for the other side of the block. Because of the way the cable distribution areas are divided up, this means that the copper distribution cables have different filling ratios [volumetric efficiencies].

The cable distribution areas formed in this manner must now be connected to exchange (HVK) 7 via main cables (Hk) 9. For example, a main cable with a net capacity of 49 copper pairs is needed to supply cable distribution area E. This means that the main cable having the next higher pairing of 50 copper pairs, which is preferably used, is utilized at a rate of up to 98%. The planner now has two choices for running the main cable of area E to exchange 7. He can run the main cable along routes to a cable distributor in an area A or D situated closer to the exchange in order to run the main cable of area E, along with the main cables of other areas, to a main cable having a higher capacity or a different technology, such as fiber optics. The planner can run the main cable of area E to

the cable distributor of either area D or A. In the first case, the main cable leading from exchange 7 to the cable distributor of area D must have a minimum capacity of 106 copper pairs (49 copper pairs in area E and 57 copper pairs in area D). In the second case, the main cable leading from exchange 7 to the cable distributor of area A must have a minimum capacity of 117 copper pairs (49 copper pairs in area E and 68 copper pairs in area D). However, since copper cables having a capacity of 117 or 109 copper pairs are not available, the copper cable with the next higher capacity, i.e. 150 copper pairs, must be selected. Using a 150-pair copper cable, the main cable capacity utilization is 70.67% in the first case and 78% in the second case. To select the optimum network version, the cost of both options must now be calculated. This procedure is repeated for all cable distribution areas.

To provide an optimum network design, all possible combinations must obviously be considered when delimiting the areas and routing the main cables. Selecting the wrong edges for the cable distribution areas in the early stages of network planning produces subsequent errors which cannot be corrected later on.

Because it can also take several weeks to set up a large network manually, and networks often must be set up under extreme time pressure, it is usually not possible to develop alternative solutions when defining the areas. The network is therefore not optimized with a view to efficient network utilization and cost minimization.

As a result, the method described above is not likely to enable the network planner to set up the most cost-effective

and profitable network variant.

Summary of the Invention

The object of the present invention is ~~therefore~~ to provide a method which can be used to generate a highly functional, low-cost network having a high level of capacity utilization in the shortest amount of time and with the least amount of work.

According to the present invention, this object is achieved by generating, in a first process step, a graph composed of edges and nodes, the graph including all technically feasible and/or definable network transmission paths, and the length and direction of the edges being derived from the real topography of the street segments and definable cable paths of the territory to be supplied by the network, and the nodes forming the intersections between the edges or streets and/or cable paths; by assigning, in a second process step, the users in the territory to the graph in such a way that each user is connected to the closest edge or the closest node in the graph by an additional service edge; by generating, in a third process step, the most cost-effective tree structure by removing unnecessary edges from the graph so that only one connection between the main distribution node and each user is provided by the edges and nodes in the tree structure; by determining, in a fourth process step, the load carried by the edges in the tree structure according to the user needs and requirements; and by dimensioning and selecting, in a subsequent fifth process step, the technologies to be used for each edge, service edge, and node in the tree structure on the basis of the edge loads calculated in the above-described process steps ~~process steps I-IV~~.

The method according to the present invention can be used to advantageously set up a network which is particularly short in length, allowing it to be generated especially economically

since the costs of materials and laying the cables are low, network capacity utilization, for another thing, being particularly high, keeping the carrier's costs low. The method can be used, in particular, for telecommunications, water, long-distance heat supply, and power networks. By converting the method to a computer program that can run on a data processing system, the generated network can be easily optimized manually later on because certain transmission paths can be permanently defined for the graph, the method being used to produce a network which routes, for example, the telecommunications equipment, in particular the cables, along these transmission paths.

A complete network plan can be generated ~~drawn up~~ very quickly by applying the method multiple times to different network levels, due to the various technologies used for the levels. If a computer is used, for example, for a telecommunication network, the cable types to be laid, as well as their lengths and pairings, are available in a database immediately upon completion of the method, along with the interconnections needed for each node. This makes it possible to very quickly generate a list of costs and materials. Maps for network construction and maintenance can also be created from the network plan data generated.

In the case of water networks, the required pipe types, along with their diameters and gradients, the necessary pumps and their locations, etc., can be determined directly.

One advantage is that all process steps can be easily completed quickly and conveniently using a computer program, making it possible to generate any number of network plans for a territory in a relatively short amount of time. An optimum network plan can be drawn up gradually by making minor changes

to the defined street and route layout parameters as well as the costs of materials and laying cables and the technology to be used for a specific network level. However, these parameters can also be defined or selected for each step in generating a network plan, using a batch program or, for example, genetic algorithms or evolutionary strategies. Using a computer makes it possible to optimize a network plan without any subsequent manual work.

Ins C7

The method according to the present invention is explained in greater detail below in its individual process steps on the basis of drawings illustrating, by example, the setting up of a telecommunications network.

Figure 1 shows a territory 1 having individual users 3 arranged along streets;

Figure 2 shows territory 1, which was manually divided into areas A-E by a network planner using conventional methods;

Figure 3 shows a network plan for territory 1, which was drawn up manually by a network planner using conventional methods;

Figures 4 through 8 show the method according to the present invention;

Figure 4 shows a graph G inserted into territory 1 using the method according to the present invention, one edge 14 for graph G being provided along each side of each street;

Figure 4a shows a section of territory 1 illustrated in Figure 4, in which the method according to the present invention connects users 3 to graph G via service edges 16;

Figure 4b shows a section of territory 1, in which tree structure Ba is created by connecting users 3 step by step to the portion of the tree structure already created;

Figure 4c shows the tree structure created for territory 1 using the method and load 21 assigned to edges 14;

Figure 5 shows territory 1 having the cable distribution sub-areas created in process steps Va) through Ve) described below;

Figure 5a shows a section of territory 1, with two cable distribution sub-areas being combined to form one cable distribution area 26;

Figure 5b shows a section of Figure 5a, cable distribution area 26 being separated from the tree structure by the two limit edges Gk.

Figure 5c shows a section from Figure 5a, the limit edge of the cable distribution sub-area being connected to closest node 29 with a requirement of 9;

Figure 6 shows territory 1 having the created cable distribution areas 26 and cable distributors

KVZ_1 to KVZ_4 arranged in their distribution centers;

Figure 7 shows new tree structure 33 created using process steps Vq) through Vs), described below;

Figure 8 shows cable distribution areas 26, pairings 35 being assigned to individual edges 14 or street segments.

For territory 1 illustrated in Figure 1, composed of city blocks 2 on which users 3 are arranged at random as well as streets and defined cable paths 5 and their intersections 6, a telecommunication network that connects territory 1 to an exchange 7 is set up using the method, as shown in Figures 4 through 8. For purposes of illustration, only those users 3 who need a service of the same type, such as phone lines, are provided.

Because the method can be applied as often as necessary to specific levels determined by the technologies, exchange 7 can, however, be treated like a distribution node 8.

Figure 4 shows a street graph which was created in process step I. It is assumed that only streets exist, and no defined cable paths. An edge 14 of graph G is assigned to each side of a street. This produces four nodes 15 at street intersections 6, a group of four street intersections 11 forming, in each case, a separate edge 14.

In process step II, which is illustrated in Figure 4a, users 3 are connected to graph G using service edges 16. For this purpose, either the shortest path to graph G from the junction

of particular user 3 must be selected, or service edge 16 must be run along a specific route according to a particular preset parameter, thus determining the length of service edge 16. Where service edge 16 meets an edge 14 of graph G, this edge 14 is split into two edges 14a, and the junction formed by edge 14 and service edge 16 becomes a new node 15a. Edges 14a thus correspond to edges 14.

At the end of process step II, all users 3 are connected to graph G. As shown in Figures 4b and 4c, a tree structure Ba is generated in process step III, each user 3 being connected to exchange 7 via a separate connection, which is composed of service branches 16, edges 14, and nodes 15. For this purpose, graph G is searched for user 17 having the lowest cost of connecting to exchange 7. The connection costs are determined, for example, by the cable technology used and the cost of laying the cables, including the excavation costs. This user 17, edges 14, and nodes 15, which connect the latter to exchange 7, are then marked and form marked transmission path 18 (process step Ia). Next (process step Ib), all users 3 are connected to exchange 7 in succession so that user 19 whose cost of connecting to previously marked transmission path 18 is lower than that of all as yet unmarked users 3, is always connected to exchange 7 first, taking into account previously marked edges 14 and/or nodes 15. The located transmission path is marked along with its user. Process steps la and lb are composed only of simple search algorithms and can be easily applied in the form of a computer program.

Once all users 3 have been marked, i.e., are connected generated tree structure Ba, all unmarked edges 14 and nodes 15 of graph G are eliminated. Instead of eliminating edges 14 and nodes 15, however, it is possible to use only marked edges

14 and nodes 15 for the remaining process steps. The latter variant certainly preferable from a programming standpoint.

Generated tree structure Ba is designed to minimize the connection costs (material and cable laying costs) for the defined, possible routes and cable layouts 5 in territory 1.

When designing a computer program, it can be useful to assign a load 21 to remaining edges 14 of tree structure Ba in process step IV. One possible algorithm is described below. In carrying out the method, however, it makes little difference if a different algorithm is used, and, in each case, if necessary, load 21 of edges 14 is determined in process step V.

The possible algorithm is designed so that load "O" (zero) is initially assigned to all edges 14 of tree structure Ba, moving consecutively from each user 3 to exchange 7 along edges 14 and nodes 15, adding requirement 4 of user 3, where the procedure was last started, to each edge 14 traveled.

After the optimized tree structure or route graph has been drawn up using the process steps described above, the way in which users 3 connected to tree structure Ba are combined into cable distribution areas 26 is described below (Figures 5 and 6), the method continuing to "optimize" the graph by generating as few cable distribution areas 26 as possible by utilizing the equipment as efficiently as possible.

To generate cable distribution areas 26, the capacity of the individual cable distributors supplying the individual cable distribution areas is first defined (process step Va). This capacity depends on the technology of the cable distributors

used. The capacity determines the maximum number of copper pairs, glass fibers, etc. available for a cable distribution area. The maximum ranges of the transmission equipment to be used in cable distribution area 26 must also be defined, thus limiting the size of cable distribution sub-areas 23 in process step Vb).

Depending on his requirements 4, an individual user 3 can form a single cable distribution subarea 23 or even a separate cable distribution area 26, in which case the requirements can be greater than the capacity defined in process step Va). It is advisable to define these users 3, whose requirements 4 are greater than the cable distributor capacity specified in step Va, as a single cable distribution area 26, each of these users 3 being assigned enough transmission equipment to cover the user's requirements so that node 15 bordering on limit edge Gk of a user 3 of this type is assigned a requirement corresponding to a multiple of the capacity defined in step Va for new tree structure 33 to be created in process step Va), just covering the requirement of user 3; and to then remove this user 3 from tree structure Ba, the node forming the distribution center or location of the cable distributor assigned to user 3.

All markings are subsequently removed from users 3, provided that such markings were previously set.

Tree structure Ba is then searched for an as yet unmarked user 22 located at the end of a branch of tree structure Ba. This user 22 is identified by the fact that the user, along with his service edge 16, is adjacent to a node on which only one edge 14 borders. Starting from this user 22, the planner moves along service edge 16, edges 14, and node 15 in the

direction of exchange 7 until reaching a limit edge Gk. A limit edge Gk is identified by the fact that it is connected to a node 15 bordering on an edge 25 whose load 21 is greater than the load defined in process step Va). An edge 14 can, however, become a limit edge Gk of a cable distribution sub-area 23 as soon as the range, starting from user 22, of the transmission equipment to be used for this cable distribution area 26 (which is also defined in process step Va)) is exceeded, even if limit edge Gk would seem to belong to cable distribution sub-area 23 based on its capacity.

Figure 5 shows all cable distribution sub-areas 23 that are created with the method described. Note that this breakdown into cable distribution sub-areas 23 is unique and can be reproduced.

Using subsequent process steps Vf) through Vp), cable distribution sub-areas 23 are now gradually combined or transformed, if possible, into cable distribution areas 26, making sure that load 30 of combined cable distribution area 26 does not exceed the maximum capacity of cable distributor 8. At the end of these process steps, each user 3 is then clearly assigned to a cable distribution area 26.

When creating cable distribution areas 26, it should also be noted that only adjacent cable distribution subareas 23 can be combined, since the areas will otherwise lack cohesion. This would make it nearly impossible for the carrier to perform maintenance and error analysis work later on because conclusions as to the causes of errors that arise could no longer be made in the event of a malfunction. Areas are adjacent when they border on the same node 15 and lie directly against one another in a clockwise or counter-clockwise

direction.

Process steps Vf) through Vp) are explained in greater detail below with respect to ~~on the basis of~~ Figures 5 and 6, Figure 5 depicting the initial situation on which process step Vf) is based, and Figure 6 depicting the end result after completion of process step Vp).

In process step Vf), those cable distribution sub-areas 23 in tree structure Ba are first selected which cannot be combined with any adjacent cable distribution sub-area 24 having a smaller or equivalent load, to form a larger cable distribution sub-area 23 because the total load of both adjacent cable distribution sub-areas exceeds the cable distributor capacity. These cable distribution sub-areas 23 are transformed into cable distribution areas 26 and are removed from the tree structure in process steps Vh) and Vi), the requirements of this new cable distribution area 26 being subtracted from all edges 14 connecting the latter to exchange 7 and ignored when creating the other cable distribution areas 26. ~~Refer to the claims for a detailed description of process steps Vh) and Vi).~~

Below is a description of how cable distribution sub-areas 23 are combined into larger cable distribution sub-areas 23. As illustrated in Figure 5, the three cable distribution sub-areas 24 are adjacent to the same node 28. None of the three cable distribution sub-areas 24 has yet been affected by the previous process steps since their requirements either do not exceed the cable distributor capacity, or the sum their capacities and that of the adjacent cable distribution subarea does not exceed the cable distributor capacity. The requirement of one cable distribution sub-area 24 can

therefore be derived directly from its limit edge Gk. For example, the three cable distribution sub-areas 23 bordering on node 28 have requirements 9, 77, and 20. The sum of adjacent cable distribution sub-areas 23 yields either 86 or 97. In a subsequent process step, cable distribution sub-areas 24 are then combined into a cable distribution area 26 whose total is the largest, i.e., the two cable distribution sub-areas having a total requirement of 97. This cable distribution area 26 is now separated or removed from the tree structure and/or ignored for the remaining process steps (Figure 5b). If more cable distribution sub-areas 24 were attached to node 28, they could also be combined. However, attention must be paid to ensuring network cohesion. In the current example, however, only one single cable distribution sub-area 24 is attached to node 28. Limit edge Gk of this cable distribution sub-area is now run in the direction of exchange 7 until its end facing away from cable distribution sub-area 23 meets next node 29, to which another cable distribution sub-area 23 is attached. Starting from this next node 29, the load of cable distribution area 26 eliminated earlier is subtracted from edges 14 in the direction of the exchange (Figure 5c). Cable distribution sub-areas 23 continue to be combined until there are no longer any cable distribution sub-areas 23 attached to tree structure Ba. ~~The exact method for combining cable distribution sub-areas 23~~ As shown in Figure 6, the ~~into cable distribution areas 26 is described in the claims (process claims Vj) through Vp)).~~ ~~As shown in Figure 6, the~~ method according to the present invention is used to divide the territory into four cable distribution areas 26.

After users 3 have been assigned to created cable distribution areas 26, the individual distribution cables (VzK) connecting the cable distributors to assigned users 3 can be dimensioned.

Process steps Vu) through Vw) are completed for this purpose. Process step Vu) is the first step in dimensioning. Process step Vu) is the initialization step, assigning load "O" (zero) to all edges 14, 37 of tree structure Ba. Requirement 4 of each user is then added in step v), moving along edges 14, 37 from users 3 and along node 15 to the cable distributor of cable distribution area 26 belonging to user 3. In doing this, note that the cable distributors should, if possible, be located in the distribution center of the cable distribution area, the center being mapped to the next node to prevent additional nodes from being created in the network. The distribution center is determined by the profitability of the center to be moved and can be calculated, for example, by distributing users 3 and their requirements 4. A variety of algorithms are known for determining the location of the distribution center or cable distributor, and they can also be used in the method according to the present invention.

In step Vw), a distribution cable VzK, which corresponds to a pairing and whose capacity just covers the load of edge 14, is then assigned to each edge 14, 37. This produces a network plan see (Figure 8) for the individual cable distribution areas which immediately reveals which technology or which pairing 25 must be used for cable 34 to be laid, in order to adequately supply the users connected to that cable.

The dimensioning of individual cable distribution areas 26 is thus concluded.

Next, the cable distributors of cable distribution areas 26 must be connected to the exchange. If territory 1 is large, however, it may be necessary to provide additional distribution nodes to supply the cable distributors of cable

distribution areas 26 created first and to combine distribution areas into a new network level. In both situations, process step V can be applied to the tree structure illustrated in Figure 7, although without indicating the requirements of individual users 3, but rather the requirements of cable distribution areas 26 of the previous network level, which is selectively represented by the cable distributors attached to the tree structure. Loads 31 of the edges can again be determined, and cable distribution sub-areas as well as cable distribution areas formed on the new network level. The method can continue to be applied to this network level.

A slightly modified version of the method can also be applied to networks in which the different requirements of the users make it necessary to provide multiple pieces of equipment side-by-side on a network level, the equipment being connected to exchange 7 on the next higher or lower network level, using a single piece of equipment. At the same time, this is also taken into account when delimiting cable distribution sub-areas 23 and cable distribution areas 26.

Those skilled in the art can easily apply the described method according to the present invention to other network systems, such as a long-distance heat supply or water supply network. In these networks, the pipes are also run along routes or streets which are combined or distributed at street intersections. According to the method, these junctions are defined as nodes 15 and the pipe routes as edges 14. Exchange 7 is replaced by a main distribution node of the long-distance heat supply network. Because the requirements represent an abstract number in the method, and the long-distance heat supply requirements of the individual users can also be

represented by a number, the method does not need to be changed in this regard, for example in order to apply it to a long-distance heat supply network.

List of reference numbers:

1 Supply territory

2. City block

3. User

4. User requirements

5. Streets or defined cable path

6. Street or cable intersection

7. Main distribution node (HVK) or exchange (Vst)

8. Distribution nodes (KVZ_A -KVZ_E = cable distributors for areas A-E)

9. Cables with data lines

10. Transmission line to user

11. Street intersection with cable run underground.

12. Cable path to main distribution node.

13. Cable for area E is laid in a cable pit together with part of the cable for area D

14. Edge representing one side of a street

15. Node, junction for the edges (14)

16. Service edge to user

17. User with the lowest cost of connection to the exchange (HVK, 7)

18. Marked transmission path from the exchange (7) to the user (17)

19. User with the lowest cost of connection to marked transmission path 18

20. Users subsequently connected to the previously marked edges (14) and nodes (15) using the method

21. Load on the edges (14)

22. User in process step Vb)

23. Cable distribution sub-area

24. Cable distribution sub-areas (23) whose limit edges (Gk) are attached to the same node

25. Edge in process step Vc)

26. Cable distribution area in process step Vg)

27. Eliminated cable distribution area, process step Vh)

28. Node bordered by the limit edges (Gk) of multiple cable distribution sub-areas (23)

29. Closest node; process step Vi)

30. Requirements of a cable distribution area (26)

31. Load of edges (23)

32. Edges of the new tree structure (33) created in process step Vs)

33. New tree structure created in process step Vs)

34. Distribution cable (VzK)

35. Pairing of distribution cable (34)

36. Node shared by the two cable distribution areas 2 and 4 in which the distribution cables of both cable distribution areas run parallel

37 Edge

A-E Areas in supply territory (1)

Ba Tree structure

CuDA Copper pair

Cu-VzK Copper distribution cable

Gk Limit edge of a cable distribution sub-area (23)

Hk Main cable

HVK Exchange (7)

KVz Terminal for the distribution cable of the cable distribution area

Kvz area Cable distribution area

VzK Distribution cable (34)